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DESCRIBES NEW SOVIET CALCULATING MACHINES;
PENZA PLANT TO SERIES PRODUCE ELECTRON TUBE INTEGRATOR

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The field of computing-machine building is making its first strides in
the development of mathematical devices for mechanizing complex, labor-consum-
ing calculating and statistical accounting processes in the solution of mathe-
matical problems in scientific research and planning organizations. To this
field belong not only machines for mechanizing mass operations, but also unique
and highly specialized apparatus for individual laboratories and scholars.

A considerable number of research and planning institutes, bureaus, and
laboratories have not yet formulated or submitted their requirements for such
modern facilities as instruments for recording observations in the study of
processes, mechanisms for registering and averaging the numerical values of the
experimental data observed, devices for calculating mean quadratic deviations,
etc. These facilities present great opportunities. The use of a simple, inex-
pensive mechanism in many cases would have greatly changed the conditions of work,
accuracy of results, and productivity.

Mathematical machines can be divided into two main groups, devices for sep-
arate computations, and modeling mechanisms. Only certain well established types
of modeling devices will be treated in this article, in a brief and general way.

Many of the mathematical functions of natural, physical rules, expressed in
equations, cannot be solved in the usual form or by the usual mathematical meth-
ods, even in special cases, because of the complex, labor-consuming computation
operations involved. Modeling devices facilitate and accelerate many times the
solution of such problems; they also make possible the solution of complex equa-
tions and systems of equations which could not be solved without the new technique.
The analogical method is based on the design and operation of modeling devices.

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If research discovers in mathematical formulas which express relationships between physical magnitudes in any new field an analogy to known formulas obtained in earlier research in another field, experimental checking of the results obtained will indicate whether it is possible to get the proper solution by analogical means.

According to V. I. Lenin, "The unity of nature appears in the astonishing analogousness of differential equations pertaining to the different fields of phenomena." In connection with the use of the analogical method, Academician A. N. Krylov states that the equation used for computing the movement of the heavenly bodies and their attraction to the sun is identical with the equation used to calculate the rolling motion of a ship on the sea.

The following expressions examplify a simple mathematical analogy:

$$F_1 = \frac{m_1 m_2}{r^2} K_1;$$

$$F_2 = \frac{i_1 i_2}{r^2} K_2;$$

$$F_3 = \frac{m_1 m_2}{r^2} K_3.$$

The first formula is the law of universal gravity; the second, Coulomb's law for electrostatics; and the third, Coulomb's law for electromagnetism. In all three formulas, K is a constant, depending on the dimensions involved.

In electrical engineering, in the study of transmission lines under changing conditions of length and resistance, such lines may be replaced by an equivalent substitution scheme consisting of a definite combination of resistances, condensers, and choke coils. In an established method of work, electrical machines, transformers, and other elements of electrical installations can be represented by equivalent substitution schemes of coils and condensers. In the same way, many mechanical devices such as engine shafts, beams, and girders, in the study of certain processes, can be replaced by a system of springs, masses, dampers, and levers.

In the simplest types of equivalent oscillating systems, the source of mechanical power is analogous to the source of electric current power; the springs, to the inductance; the damper, to the resistance; and the mass, to the capacitance.

Newton formulated the theory that in dynamically similar systems, corresponding forces have the same ratio as the product of the square of the corresponding lengths, the square of the corresponding speeds, and the first power of the corresponding densities. Such ratios are designated as criteria of similarity. Criteria of similarity are necessary for the construction of models.

Not until 200 years later did Academician A. N. Krylov and other Russian scientists make use of Newton's theory. They developed it along materialistic lines, adapting all the valuable points of the doctrine to modern technical conditions.

Empirical checking on models which are of identical physical nature with the original is not always possible. It requires a great deal of time and money. More important, it is not sufficiently accurate, and may even distort the known phenomenon. Therefore the tendency has been to model in that field of physics where the process is most convenient and simple, where it is possible to get a

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certain universality of model, and where, finally, a model can be constructed which makes it possible, by simply matching invariable coefficients and other conditions of the equation, to solve an equation which does not admit of solution in the ordinary form. It follows that dynamical models must be used, which transmit the dynamics of the phenomenon and the process, and that the models themselves must be utilized ad "slide rules" of the highest class.

Thus, a number of models have been developed which are characterized by the class or type of differential equations in mathematical physics to which they are analogous and which perform the modeling as a method of experimental research into physical processes under conditions formulated with mathematical accuracy. A number of these designs can be carried to such a point of accuracy and productivity that some of them can be conditionally adapted to the class of mathematical machines used for numerical integration of differential equations.

The nature of the magnitudes to be used by the machine to express the conditions of the problem and the results in its solution determine the principle of design and the type -- mechanical, hydraulic, electric, etc.

Three systems of electromechanical analogy are known. The most recent and efficient at present is the third system of electroanalogy, worked out and formulated by L. I. Gutenmakher, which makes it possible to represent all the unknown variables in the mechanical system by only one physical magnitude -- voltage at specific points along the electric circuits. The voltage at one point in the circuit corresponds to the permutation; at another point, to the speed; and at a third point, to the mechanical power.

The number of variable magnitudes in the model has not, on principle, any limitations.

Each of the types of modeling devices mentioned is clearly represented in the USSR. The priority of Russian scientists in each of these branches is indisputably confirmed. However, the most highly developed, not only for all scientific research activities, but also for engineering practice, are the electron tube models and integrators developed at the Academy of Sciences USSR by the electromodeling laboratory under the direction of Gutenmakher.

Model ELI-14 (6) is being put into series production by the Ministry of Machine and Instrument Building USSR at the Penza Computing-Analyzing Machine Plant. /The (6) appears to indicate that the machine will solve one equation of the sixth degree or its equivalent./

The electron tube integrator, Type ELI-14, developed by L. I. Gutenmakher and N. V. Korol'kov, is a table model intended for analyzing physical processes and technical principles, when this analysis can be reduced to an approximate solution of a system of six ordinary linear differential equations with constant coefficient of the following type (I):

$$b_1 \frac{dx_1}{dt} + a_{11}x_2 + a_{12}x_2 + a_{13}x_3 + a_{14}x_4 + a_{15}x_5 + a_{16}x_6 = a_1;$$

$$b_2 \frac{dx_2}{dt} + a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + a_{24}x_4 + a_{25}x_5 + a_{26}x_6 = a_2;$$

$$b_3 \frac{dx_3}{dt} + a_{31}x_1 + a_{32}x_2 + a_{33}x_3 + a_{34}x_4 + a_{35}x_5 + a_{36}x_6 = a_3;$$

(I)
$$b_4 \frac{dx_4}{dt} + a_{41}x_1 + a_{42}x_2 + a_{43}x_3 + a_{44}x_4 + a_{45}x_5 + a_{46}x_6 = a_4;$$

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$$b_5 \quad \frac{dx_5}{dt} + a_{51}x_1 + a_{52}x_2 + a_{53}x_3 + a_{54}x_4 + a_{55}x_5 + a_{56}x_6 = a_5;$$

$$b_6 \quad \frac{dx_6}{dt} + a_{61}x_1 + a_{62}x_2 + a_{63}x_3 + a_{64}x_4 + a_{65}x_5 + a_{66}x_6 = a_6;$$

under the arbitrary initial conditions $x_{10}=a_{10}$; $x_{20}=a_{20}$; $x_{30}=a_{30}$; $x_{40}=a_{40}$; $x_{50}=a_{50}$; $x_{60}=a_{60}$, assigned where $t - 0$. Here t is an independent variable (time); x_1, x_2, x_3, x_4, x_5, x_6 are six dependent unknown functions of time (t), that is, unknown voltages at specific points in the scheme of the integrator in relationship to the neutral point (earth).

One equation of the sixth degree can be easily reduced to the form of (I); this is also true of high-degree equations with constant right-hand members, the sum of the degrees of which does not exceed six, as the following: (1) a system of three equations of the second degree, (2) a system of two equations of the third degree, and (3) a system of two equations, one of the second degree and one of the fourth degree, etc.

In the ELI-14 integrator, the values for a, with any index, can be set up by the commutators of boosting blocks, arranged in groups, with three blocks each on the right and left. In each of the six boosting blocks are 17 movable carbolite coils. Twelve of these coils serve for the assignment of coefficients of a, within the limits -1 to +1, and within /a margin of error of/ 0.01; four of the lower coils are intended for assigning the coefficient of b, within the limits 0.1 to 6, and within /a margin of error of/ 0.1. The error in setting up the values for a and b does not exceed the magnitudes ±0.01 for a and ±0.1 for b, which amounts to ±1 percent of the maximum possible value of the coefficients, 1 for a and 10 for b.

There is also a commutator for assigning the original values of the functions for the moment of time $t = 0$, and another for assigning the right-hand members of the equations, which are invariable.

Before being solved on the integrator, the given system of equations must be converted to the type of system (I), and the latter recorded in matrix form. The solution consists of setting up the given magnitudes for a and b by means of the commutators, and measuring the proper pressures. Qualitative analysis of the curves obtained can be made by means of a cathode ray oscillograph, which makes it possible to obtain all the unknown variables in the function of time, and the functional dependence of each unknown variable upon any of six others. Integral curves can be photographed from the screen of the cathode ray oscillograph. More accurate photographing can be done by using a loop oscillograph, and more accurate measuring by a device for measuring instantaneous values at any point.

The solution obtained in one part of the integrator can be assigned as the right-hand components of equations which are being solved in another part of the integrator. Thus, equations can be solved which have right-hand members of the type: kt; $1-kt$; etc. The utilization of part of the apparatus for obtaining right-hand members in the form of functions of time lowers accordingly the permissible degree of the equation in process of solution.

Dimensions of the machine are 1,150 x 890 x 635 millimeters. The weight is 280 kilograms. Operation of the apparatus requires a direct current of 200-300 volts (stability ±0.5 percent, ground 0.1 percent), and current power of 0.8 ampere; or alternating current of 127 volts (±2 percent) and current power of 3.5 amperes.

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The ELI-14 integrator is designed for the analysis of transitional proc-
esses in acutal engineering installations, machines and apparatus. The equa-
tions which express the physical processes in such systems are characterized
by the fact that small variations in the coefficients, original conditions,
and disturbances have no appreciable effect on the character of the transi-
tional processes. The assignment of specified parameters is done in engineer-
ing practice on the basis of computation or measurements. In actual installa-
tions, as a result of small outside influences which are always present, and
to unavoidable fluctuations, the pertinent right-hand members and the original
conditions of the equations depicting these installations vary within certain
limits. No installation remains unchanged when these processes are taking
place within it.

If, in the examination of a concrete problem, definite physical values are
assigned to the parameters, this has meaning only on condition that the small
variations in the parameters do not substantially change the character of the
motions, and that the pertinent features are preserved in the behavior of the
theoretical model. Such behavior characteristics as are not retained in the
model in the case of small variations in the form of the differential equations
and the magnitudes of the parameters, have no physical interest, since they do
not reflect the properties of the actual physical system. Those systems whose
intrinsic components remain unchanged serve as theoretical models of actual
physical systems.

The ELI-14 integrator, which is intended for the study of transitional
processes in actual installations, can be utilized for the following purposes:

1. For studying transitional processes in electrical systems, machines, and
apparatus, particularly for computing such data under emergency conditions and
commutation processes; also for analyzing transitional processes in synchronous
generators, and over-voltage and short-circuit conditions in electrical installa-
tions (with linear interpretation of the problems).

2. For studying transitional processes in mechanical, acoustical, and re-
ceiving-amplifying installations.

3. For studying tracker systems in the pertinent technical fields.

4. For planning, designing, and tuning modern systems of automatic regula-
tion and control in widely different technical fields -- energetics, mechanics,
optics, thermotechnics, metallurgy, etc.

5. For illustration purposes in courses in mechanics, mathematics, ener-
getics, construction work, etc., in higher technical schools and universities.

Basic errors in the solution of problems on the ELI-14 are due to the fol-
lowing factors; an error in assigning the values of the coefficients, the ini-
tial conditions, and the right-hand members; an error as the result of frequency
or nonlinear distortion in the boosters, or to instability of the amplification
factors of the boosters; an error in converting the equations; an error due to
the loading of voltage dividers with currents through coupling resistances; or
an error in measuring results.

It is difficult to take account of these errors. To simplify statement of
the problem, they are ascribed to the coefficients. A resulting error of this
type usually does not exceed 1 percent of the maximum value of the coefficients.

The measurement error in photographs taken from a screen when cathode ray
oscillograph EO-5 is used amounts to 10-15 percent; the measurement error in os-
cillograms of the loop oscillograph is from 2-5 percent; the measurement error,
when a measuring device is used, is 0.5-2 percent in amplitude and 2-5 percent
in time, depending on the form of the curve of the transitional process.

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The error in matrix-conversion can be reduced to a significantly rational conversion, and by increasing the absolute magnitude of the majority of coefficients to the maximum value.

The approximation error in the coefficients at no time amounts to more than ±0.5 percent of the value of the maximum coefficient.

Those problems, in the solution of which an error takes the same form as an error in the assigned coefficients, initial conditions, or right-hand components, appear most significant in practical research in engineering installation. However, it can be generally estimated that the work of the integrator, from the point of view of the accuracy of the coefficients, is within the limits of ±1 percent of a and b. There may be cases, nevertheless, where greater accuracy than this is required.

The time consumed in solving a problem on the ELI-14 includes the time required for converting the equations to a form convenient for solution; for adjusting and checking the integrator; setting up the magnitudes for a and b; observing and taking measurements; computing the scales; repeatedly setting up the problem and comparing the solutions in order to eliminate accidental errors and finally, studying the effect of variation of the parameters.

The conversion of the equations is determined by the character of the problem, and may take 10-15 minutes, or in certain complicated cases, several hours.

The integrator operates steadily through an 8-hour working day. About 30 minutes is required for adjusting and checking the parts.

The solution of a problem takes from 10 to 30 minutes. It then appears on the screen of the cathode ray oscillograph in 0.1 second. The measuring of a single instantaneous value with the help of a measuring device requires not more than 30 seconds. Photographing from the screen of the cathode ray oscillograph takes about one minute for one print; recording with a loop oscillograph, approximately the same time. Computing the scales takes from 10-15 minutes, and switching to the solution of a new variant, about one minute.

Measuring and photographing are done as a rule only for variants obtained by the cathode ray oscillograph.

Experimental models of electron tube integrators of the ELI type were put out in 1948 and 1949. In particular, the ELI-24 was produced, for solving 24 analogical differential equations of the (I) type. It is also possible to assemble the proper quantity of blocks for a different number of equations. The ELI-12, for example, is used to solve a system of 12 differential equations of the (I) type.

Electronic integrator EI-12 serves for the solution of differential equations in partial derivatives of an elliptical type, under arbitrarily assigned conterminous conditions. Examples of such an equation are the equations of Laplace and Poisson, and equations of vector potential. Under the proper conterminous conditions, solution of the frequently encountered problems of Dirichlet and Neumann is often possible.

Hydraulic integrator IG, the method and basic principles of which were stated by Professor V. S. Luk'yanov in 1934, and the first examples of which were assembled in 1935, is used for studies and computations of a large class of phenomena and processes mathematically characterized by the ordinary form of differential equation in partial derivatives.

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It is significant that a given equation is solved under any cont rainous conditions assigned numerically or graphically. The equation must be represented in finite differences. The analogical method here is to produce variations in water level in the pipes of the installation which represent, in the specific scales of height and time, variations in the magnitudes being studied -- temperatures, pressures, and other potential functions. For example, in calculating temperature variations in a solid, the areas of the cross sections of the containers correspond to the heat capacities of the elemental volumes; the hydraulic resistances of the elements connecting the vessels correspond to the thermal resistances between the elemental volumes; and the discharge of water, to the flow of heat.

An experimental plant model of single-measuring hydraulic integrator, type IG-1 is being suggested for production in 1950. These single-measuring devices are to be widely recommended for demonstration purposes in training institutions.

A larger, double-measuring type of hydraulic integrator, the IG-2 (1941 - 1945), consists of ten units, two devices for assigning conterminous conditions, five "aquariums" with floating vessels, and two sources of supply. In 1951, after improving and perfecting the design for production, it is planned to put out an experimental form of the IG-2.

The hydraulic integrator of Professor V. S. Luk'yanov can be widely used in various fields of science and technology -- for studies and calculations in connection with the effect of temperature factors upon the durability of architectural installations; for analyzing the thermal stability of rooms; for studying the processes of water filtration in the soil (for purposes of land reclamation, geological engineering, etc.); for computing the deformations of masses of earth; for studying irregular thermal phenomena in making estimates on heating equipment; for calculations in the metallurgical and metalworking industries; for computing temperature behavior of the soil under various climatic conditions, with different types of soils and surface heating; for calculating the temperature factor in building railroad cars and locomotives; and for computations involving the preservation and drying of wood.

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